***A leading edge flap wiring harness** in an S-3 wingfold area, spread out so individual wires can be viewed. Translucent material appears to be self-vulcanizing silicone tape, apparently used as a temporary repair, according to Navy sources.*

Unsafe Aircraft Wiring Poses Expensive Problem

Billions of dollars are likely to be spent before this bureaucratic web of deficient wire selection, sole source intrigue, and unexpected production stoppages is clarified. And, electronic equipment manufacturers may find themselves right in the middle of the controversy.

By Richard V. Hartman

About 2,000 combat aircraft now in service are equipped with seriously deficient wire, which can cause catastrophic aircraft control failures. Although no crashes ae known to have occurred because of the wiring problem, literally hundreds of electrical failures have been attributed to cracked, corroded, and frayed aircraft wiring. These incidents include numerous in-flight fires and inadvertent actuation of critical control elements, such as speed brakes and autopilots.

Commercial aircraft may also have experienced fires caused by using the same types of wire; and, several companies are now changing to different, more durable wire. Yet in military aircraft, faulty wire is frequently replaced by the same, inadequate type of wire, while a lengthy technical—and bureaucratic—debate continues over which wire to select as a replacement.

Replacing aircraft wiring will cost billions and take years, if a decision is ever made mandating a complete refurbishment; a problem so severe, it is

leading to what one defense official termed "a watergate-type coverup."

Details emerged after a lengthy investigation by DEFENSE ELECTRONICS, initiated when it was first learned that the Navy would spend upwards of $1 million each to rewire F-14 fighters (See *DE*, Sept. 1982, p. 30). Details from government documents, memorandas, and interviews with government and industry officials show the problem to be widespread, and no solution is yet found.

Deficient Wire

Problems arise from use of a pair of polyimide-insulated electrical wires called Poly-X and Kapton, now deemed unsuitable by DOD officials for use in modern, high performance aircraft. Poly-X is no longer in production, although large stock piles are being used to replace worn-out Poly-X. Kapton, one of the prime replacements for Poly-X, is still being manufactured by several companies.

Documents obtained by *DE* show that cracking and embrittlement of Poly-X and Kapton wiring harness insulation, especially in exposed areas, is widespread throughout the services, and has caused short circuits in key aircraft systems. Many military aircraft are flying today with cracks in the insulation of wiring harnesses down to the metallic conductors, and are only replaced when a problem occurs as a result of this dangerous situation.

The replacement for Poly-X (Kapton) is also under fire in some quarters.

According to a defense official who declined to be named, "The real cost of overcoming this situation, when all the labor and materials are added, could be several billion dollars. You won't find all these numbers in line items, because many will be included in O & R (overhaul and repair), OSIP (operational and safety improvements programs), and O & M (operations and maintenance) items." Investigators, representing the Department of Defense, have been looking into the Kapton problem and have stated that documented proof is missing, and that other factors could have caused these mishaps. Yet, the Navy Safety Center in Norfolk, Virginia, is said to have 791 wire and connector related mishap reports on file, for 1978 through 1982, of "mostly minor" incidents, relating to broken, corroded, cracked, and frayed wires. Experts directly involved in day-to-day operations also vigorously deny this so-called DOD sponsored whitewash. Documents in *DE*'s possession show that first line fighter aircraft, as well as patrol, ASW, attack, transport, and helicopter aircraft are subject to Poly-X or Kapton wiring problems. Aircraft involved include: F-14, F-15, F-4, S-3, E-2C, P-3C, EA-6, SH/UH-60, AH-64, and AH-1 models. Representatives from American Airlines and TWA are participating in the investigations, and mention of in-flight fires in their aircraft was also made. Harried military maintenance men are reported to be resorting to wrapping the most obvious defects with electrical tape as a short-term fix, hoping to reduce the probability of catastrophic short circuits.

Adding to the confusion are allegations by the Aerospace Industries Association that 726 wire configurations now listed as military standards could be reduced to three wire types in a total of 33 configurations. Other sources state that maximum temperature ratings of some wires are about 33 percent higher than will work in practice; that large percentages of wire purchased by the Defense Industrial Supply Agency for use by field forces failed basic acceptance tests; that the wires now considered chiefly responsible for the reported failures (Poly-X and Kapton) are still being used extensively in the field to repair failures experienced with the same type of wire; and, that the Kapton replacement for Poly-X shows susceptibility to water and high pH cleaners, excessive stiffness, and difficulty in usage with mil.-standard connectors.

The wire that most experts say could solve all these problems, Raychem 55, uses a patented copolymer, irradiated insulation jacket that costs about the same as Kapton. DISC states that Raychem 55 costs over $31/foot, or about 20 times that of other wires; but sources who have purchased the wire directly from Raychem dispute this widely disseminated statement as a possible clerical error. A few other experts attach more sinister connotations. Raychem's patents are the source of some conflict, since sole source commodities must have their mil.-standard specifications cancelled. Some aircraft owners, such as Petroleum Helicopters, Inc., that use helicopters as transportation to and from off-shore drilling rigs, rewired their aircraft with the Raychem product. They report this decision reduced downtime by about 50 percent.

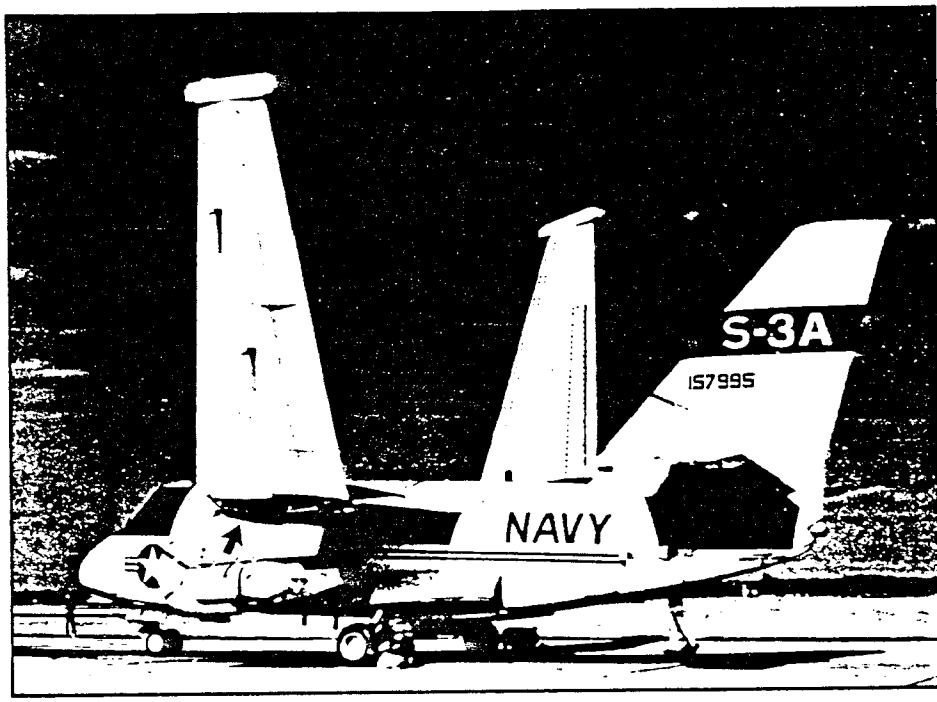
One of the earlier reports regarding aircraft wiring failures was contained in the U.S. Navy's Naval Avionics Center (NAC) Materials Test Report 4-78. This report noted that the number and types of chemical fluids used in the field far exceeded the number and types required in existing qualification testing specifications. It also noted recent field failures of wire on the Navy F-4 and F-14 aircraft. A hand written note was added by a DISC official: "F-15 failures 16-18 Poly-X," and "Sep 75 20-25 Stilan F-4 cracking." (Ed. note: No known F-15's are wired with Poly-X, and

fewer than 10 F-4's were rewired with Stilan.)

Groundwork for compounding the aircraft wiring problems began in 1975, when Raychem, the sole source supplier of Poly-X aircraft wire, notified the military that Poly-X would no longer be manufactured due to non-availability of a key ingredient. Raychem recommended substitution of a new wire type, Stilan, which, according to their letter, had better material characteristics and would be available at a lower cost. After approval for this changeover had been initiated and the wire in use, Raychem notified the military in July 1976 that Stilan production was ceasing due to economic and environmental factors. Stilan was also a sole source Raychem product; this left the military with no approved wire sources of the types previously available in the Poly-X and Stilan configurations. It was not until March 1977 that the military specifications covering Poly-X and Stilan were cancelled.

In the meantime, a special meeting of the Society of Automotive Engineers (SAE) A-2H subcommittee was held at the Navy's request to recommend substitute wires and specifications for use by manufacturers who had previously specified the cancelled wire, and for those who needed to specify wire for future construction. Thirty-six members of the producer and user industries and government were present. Results from the meeting did little to solve the problem. Recommendations were made to cancel the military specifications covering Poly-X and Stilan; and, it was affirmed that no recommendations could be made as to a substitute wire. One substitute, Kapton, was suggested, but a motion to specify it as an across-the-board replacement for Poly-X and Stilan was defeated.

During the meeting, aircraft manufacturers established their positions regarding the type of wire they were using or planned to use. Bell Helicopter noted it was using Kapton as a substitute for previously used Poly-X and Stilan. Boeing was delaying making a decision, pending further testing, but noted that some Stilan was used on its 707, 727, and 737 aircraft, which would be replaced by Kapton. About 80 percent of the wire on its 747s was Stilan, but wiring replacement for the aircraft and other aerospace applications had not yet been decided. Poly-X and Stilan type wire were used in the McDonnell Douglas A-4 and DC-10. Their replacement will probably be Kapton for the commercial aircraft, and Tefzel (MIL-W-22759/16) for the A-4. General Dynamics aircraft drawings permit use of either Stilan or Kapton. The Naval Air Rework Facility, North Island, California, used Poly-X for rewiring its F-4B aircraft, and a mixture of Tefzel and Kapton for its F-4J and RF-4B rewiring programs. Kapton is not being used where the wire encounters high pH cleaners at this facility. Grumman has replaced Poly-X wires with Kapton type in the F-14.



***The S-3 antisubmarine warfare aircraft** poses particular problems. The arrow points to th high wiring failure rate wingfold area.*

While DISC and its service equivalents wrestled with finding a suitable, but not yet designated replacement for Poly-X and Stilan, the Navy plunged other daggers into its delibrations. In a Naval Speedletter to DISC, the commander of the Naval Air Systems Command requested the supply center locate all of the Navy's Poly-X and Stilan wire, and purge them from the inventory. This summary action was requested because "concern exists that subject wire has migrated to other weapons systems and remains accessible to Navy repair activities." The Speedletter noted that Poly-X and Kapton exhibited breakdown upon exposure to aircraft cleaning solvents and "recent tests at NADC Warminste indicate insulation breakdown upo soaking in distilled water."

During 1978, proponents for Kap ton and Tefzel were maneuvering an proposing their preferred wire type with tests tending to show Tefzel ha fewer disadvantages. At the sam time, the new Raychem wire, type 55 was surfacing as a contender. The wir uses a patented radiation crosslinked extruded ethylene-tetrafluroethylen (EFTE) copolymer insulation jacke that seemed impervious to almost a chemicals it would be exposed to, an possessed admirable mechnical prope ties. However, this apparent solutio to the DOD's wiring problems ap peared to have one fatal flaw: It wa sole source. DOD regulations requir that military specifications for so source items be cancelled. In an a tempt to overcome this deficienc Raychem sent an agreement to th Air Force stating, "In event it granted a patent claiming Spec. 5 wire, and in event a military specifica tion covering Spec. 55 wire is ap proved, Raychem will grant a royalt free license under any Spec. 55 wi claims to any third party who manu factures wire for U.S. Governme end use under the military specifica tion." Initial Air Force efforts to c

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ordinate a military specification for Spec. 55 wire were rebuffed by the Navy, which recommended cancelling the project. Yet, in 1981, a Navy message stated that Raychem 55 was the preferred wire for use in service life extension programs, engineering change proposals, and standard depot level maintenance programs.

Most of 1979, 1980, and 1981 was spent in testing, maneuvering, and coordinating. During this time period, Raychem 55 wire was given designations: MIL-W-22759/32, 33, 34, 35, 41, 42, and 43. It later received national stock number designations. But, Tefzel was recommended by the Navy and Air Force as a standarized maintenance wire. It was also in this time frame that the requirement surfaced to make formal recommendations to NATO in 1982 regarding standardized aircraft wiring specifications. This proposal may have been the catalyst leading to a wiring problem solution.

The 1981 Navy message recommending Raychem 55 apparently raised a few hackles at DISC, which distributed a memorandum stating that the Raychem 55 specifications were written relying on Air Force specifications developed from Raychem data, "without technical justification or testing [by the military]." In addition it stated, there are no national stock numbers covering the wire, which means the military is procuring the wire directly from the manufacturer, circumventing Defense Logistics Agency requirements. It also noted that the temperature rating on one of the Raychem 55 wire types was raised from 150°C to 200°C, again relying on the manufacturer's data and not on DOD testing. In addition, the Air Force revised MIL-STD-454, which covers hook-up wire in military electronic equipment, to disallow use of all wire except Raychem 55. This means, according to the memo written by a DISC official, "If allowed, not only will all OEM (original equipment manufacturers) and the military be dependent on one manufacturer, but the electronic equipment installed in the aircraft as well." He continued, addressing the NATO problem, "These actions could possibly result in the same sole source manufacturer who ceased production in 1976 due to documented failures on the F-4 and F-14 aircraft and caused catastrophic supply support problems at DISC, recreating the same situation, only broadened to include NATO."

The October 1981 Navy message, however controversial, summarized field experience and laboratory testing results with some succinctness and directness (See boxed illustration). The Army Aviation Research and Development Command also entered the picture, noting that Kapton wire is being used in four helicopter types, and asked for reports on Kapton and Poly-X field experience. A TWA representative present at SAE A-2H meetings is reported to have "expressed dissatisfaction with [other aircraft manufacturers] and wire processors for what he feels is a lack of interest in continued testing *in view of reported failures and fires.*" An Air Force official reported that Langley AFB was totally dissatisfied with Kapton, primarily due to chafing and breakage of 22-26 gauge wire; Luke and Nellis AFBs are getting along with Kapton "in spite of stripping difficulties and breakage at crimp barrels." The official also reported that shrink tubing is being applied selectively over Kapton wire bundles on the F-15 to minimize chafing problems, and that Kapton wiring is being replaced on F-15 circuit breaker panels due to reported cracking and brittleness. The Navy, in May 1982, directed that all Kapton in exposed areas be replaced with Raychem 55. Despite the specifically noted failure areas, DISC reported Kapton wire users to be primarily satisfied, with most complaints coming from users who have their wire exposed to sunlight, water, and cleaning fluids. Specifically, a committee from NEMA (National Electrical Manufacturers Association) visited three Navy aircraft squadrons and installations in the San Diego area and three in the

Navy Wire Problems Most Severe

Navy carrier-based aircraft appear to be the focus of many of the wiring problems being encountered. Navy officials and experts in the wire field generally agree that the high pH factor cleaning solvents required to remove salt spray and salt-laden moisture from the aircraft are key causative factors. This, combined with the rigors of carrier landings and handling, creates a unique and very difficult wire survival environment. Technicians who inspect incoming aircraft at the Alameda, California, Naval Air Rework Facility told *DE* that most of the wire of the EA-3 aircraft arrives in good condition, except in the wheel well and wingfold areas. An S-3 inspector told *DE* that Kapton brittleness seems to be an increasing problem, and that "one or two bad ones" were detected out of every three or four aircraft during October and November 1982; primary problem areas were in the wing folds and wheel wells. In the A-6, the ac/dc relay box, wired with Poly-X, was completely rewired—with Poly-X, according to another inspector. An engineer at the same facility stated, "I can see why these Washington people would be panicking if only Kapton were available."

Navy Washington officials told *DE* that NRL is conducting an accelerated aging evaluation on Kapton. Preliminary results, he said, show Kapton begins to become brittle at an equivalent age of six to nine years. Wire is expected to last the life of the aircraft—about 20 years. "Our F-14 problems may not be over, yet," he stated. Rewiring of the aircraft has been reduced from the complete aircraft to only critical areas—and, we are recommending Spec. 55 or Tefzel 280, he said. The reason, he said, is cost and time out of service. An F-14 uses about 140,000 feet (26.5 miles) of wire for a complete set of wires, according to an industry source.

A major selling point for Raychem 55 wire, according to a Navy source, is that high heat will not cause the insulation to melt, as with other wire types. This heat resistance is a big advantage in situations where a flash fire might occur, he said, since critical systems would have a better change of continuing to work. In a similar vein, he said, previous specifications have been technical in nature. The Navy is now in the process of developing operational-type specifications for aircraft wire, in which factors such as vibration, solvent resistance, and bend radius must be addressed in order to qualify. The new specification may surface this year, he said.

—*R.V.H.* ■

Inadvertent actuation of critical control elements.

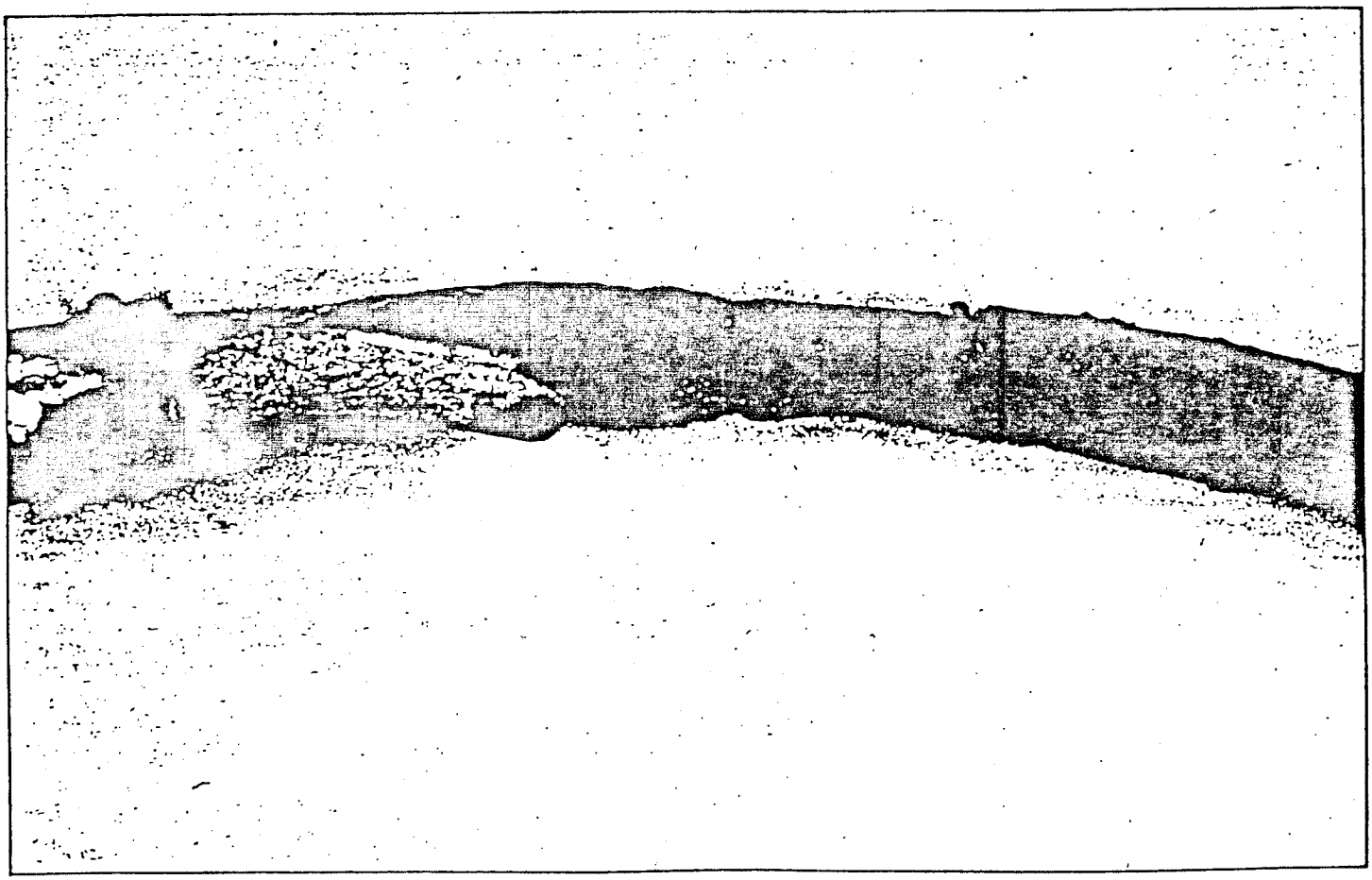
Norfolk, Virginia, area during June/July 1982, through the cooperation of the Navy. While this committee, composed of vendor wire specialists and Navy maintenance experts, found numerous Poly-X discrepancies, only a few Kapton-related potential failure areas were uncovered, according to their reports.

In response to NEMA's investigations, Capt. Donald R. Eaton, of the Naval Air Systems Command, noted a number of discrepancies in the NEMA report that could be attributed to a one-time visit as opposed to "living with the problem." Several of his comments made in October 1982 are:

- The Naval Safety Center has numerous MIL-W-81381 (Kapton) related failures. The USMC wants MIL-W-81381 removed from its F-4s at a cost of $19.6 million.
- Kapton wire does not "lay" anywhere. Because of its stiffness, it presses against the nearest surface and chafes if not clamped.
- (Regarding a severe F-4 electrical fire) This chafing was found on other F-4s inspected. NAVAIR HQ maintains this would not have happened with more flexible wire. "Too sharp a bend" for Kapton is much less than that of other, more flexible wires.
- Wingfold harnesses (in the S-3) are just one of numerous discrepant wire harnesses. NEMA failed to mention ESM harnesses, leading edge flap drive harnesses, generator harnesses, etc.
- No F-4s have been "originally wired" with Kapton. There have been seven Kapton fires in the last 18 months.

The NEMA report, although chartered to investigate Kapton failures, revealed several "horror stories" regarding Poly-X installations in naval aircraft:

- F-4s: All Poly-X wire shows severe insulation cracking down to the conductor. Operating aircraft fly with cracked insulation unless shorting is discovered.
- E-2Cs: These aircraft are wired with Poly-X. Most are a mass of insulation cracks with great numbers of these going through to the conductor. The only apparent concern is when shorting is identified.
- A-6s: Severe cracking of insulation is through to the conductor throughout the aircraft. Bare conductor is exposed for 1/16 inch in many wires throughout the aircraft, especially at the connectors, clamp points, and flex areas. Upper echelon Navy personnel talked of engine harnesses where insulation would shatter and fall from conductors adjacent to any individual wire being worked on in a harness bundle. The description of the insulation shattering closely matched the cracked and split Poly-X viewed in the A-6 aircraft. "Fuel quantity" cables cause a major problem due to Poly-X or Stilan cracking.
- F-14s: All aircraft continue flying with cracked Poly-X. It is replaced only if shorting occurs or if conductors break. It is always replaced with more Poly-X wire, since, at this location, "like wire is replaced with like



Kapton insulated wire taken from the wingfold area of an S-3 aircraft. The blackened area was determined to be caused by arcing from an adjacent wire. Insulation deterioration was stated to be caused by deterioration from weathering and from possible chemical attack by cleaning compounds.

Incorrect Reports Add to Wiring Confusion

Official documents obtained by DEFENSE ELECTRONICS relating to military aircraft wiring problems contained a large quantity of conflicting information, that in each case was reported as factual. The most flagrant example of fact discrepancy occurred in a NEMA report, which stated, "... approximately 50% of the circuit breakers on a F-14 never trip, even under severe overloads. At one time they went to a different circuit breaker manufacturer who met the required specifications, but since the circuit breakers kept tripping, they were unable to fly the aircraft; thus they reverted back to the other manufacturer." *DE* contacted Grumman, that stated, "We have not heard of this problem before." Capt. Eugene West, USN, ComNav-AirPac staff, who was reported to have made the statement, vigorously denied having made the statement "or anything remotely similar to it." He further noted that he had not been sent a copy of the report, and would like to see it so appropriate action could be taken. *DE* obliged the Captain via the next day's mail. (For other examples of conflicting information, see 'Focus' column, this issue, "Straight Scoop on Wire Prices"; and, Captain Eaton's rebuttal in the main body of this article regarding other items in the NEMA report.) —*R.V.H.* ■

wire." "There are tons of Poly-X in stock" (July 1982).

The latest definitive information is contained in a memorandum written in late August 1982 from a DISC official to the Defense Logistics Agency, laying out DISC's policy. It was signed by Col. Ben H. Swett USAF, director of engineering and standardization, and John Motz, director of technical operations. While this document is not "official," it, after four-and-a-half years, lays out the probable direction the Defense Industrial Supply Center will take toward solution of the military aircraft wiring problems.

American Airlines and TWA may have had in-flight fires.

The DISC memorandum notes that "80-90% of existing aircraft are wired with Raychem Poly-X or Stilan, not Kapton as some reports have claimed or implied." (Ed. note: Data available to *DE* shows the number is closer to 10 percent.) It states, "Every aircraft investigated to date has splits or cracks in its wiring, but the replacement wire is almost always more Raychem Poly-X, because large quantities are still available in military and civilian inventories." The memorandum discusses available types of high temperature wire, noting that none of the three is a complete substitute for either of the others. Multiple sources are available for Kapton and Tefzel, but Raychem 55 is sole source, the memo points out. Each of the three wires is given a short summary description in the memorandum:

(1) Kapton is rated at 200°C. It is lightweight and compact. However, it is susceptible to hydrazine (rocket fuel); its top coat is susceptible to chafing; and, its insulating material can absorb water. (Ed. note: The writer evidently overlooked the primary problem reported by field maintenance personnel—the stiffness of Kapton, which, in bundles, does not allow the short turning radius exhibited by wires Kapton is a candidate to replace. This appears to have been a primary causative factor, when looking at all the reports, for much of the Kapton chafing, gouging, and broken connector leads.)

(2) Tefzel is is rated at 150°C, the same as Raychem Poly-X. It is heavier than Kapton, but resists solvents and has no major disadvantages other than the 150°C temperature rating.

(3) Raychem 55 is modified Tefzel. The modifications consist of proprietary additives and exposure to electron beam radiation during manufacture. It is rated at 200°C, but that rating was based on Raychem test results. The proprietary processes increase the probability that knicks and notches will develop into cracks and splits. Raychem 55 is also heavier than Kapton.

Summarizing, the memo states, "Test data favoring Raychem 55 or casting disfavor on Kapton or Tefzel has been supplied by Raychem or through the Government agencies known to favor adoption of Raychem 55 as the standard aircraft wire." It added, "We must challenge the validity of the 200°C temperature requirement and the 200°C rating supplied by the manufacturer. The 300°C accelerated heat-aging test must also be challenged—its obvious purpose is to limit competition."

The solution to the U.S.-NATO standardization requirements were also addressed in the DISC memorandum. The recommendations suggest use of all three types of wire, depending on environmental considerations. The relatively simple "strongly suggested" solution caused one Washington observer to wonder why it took four-and-a-half years to arrive at that conclusion. The recommendations:

(1) Reactivate MIL-W-81381/1 thru 6: This is Kapton wire, with an FEP jacket to prevent top-coat chafing and humidity (hydrolosis) problems associated with plain Kapton. Limit the use of this wire to applications that are not exposed to hydrazine or other exotic solvents. The result will be a wire that weighs the same as Raychem 55, and has the same temperature rating.

(2) Designate unmodified Tefzel as the preferred wire for applications that require high resistance to solvents, provided the selecting official cannot document exposure to temperatures above 150°C.

(3) Allow the use of Raychem 55 for applications that require high resistance to solvents, provided the selecting official can document exposure to temperatures above 150°C, *and*, provided he can show the disadvantages listed will not present operational or maintenance problems. ■